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ELEMENTARY PARTICLES AND THEIR INTERACTION

D. D. Ivanenko

/Ivanenko's article is a general review of the subject of particles. The author himself is active in atomic research. Most of his material was taken from foreign literature. However this digest is confined mainly to work done in the USSR./

If some sort of interaction of space and matter is assumed, then space must have an effect on matter. A new and somewhat unexpected conclusion follows from the interdependence of both kinds of physical reality, namely, the possible assumption that matter and gravitation are interconvertible. As shown by Ivanenko and Sokolov, relativistic quantum mechanics leads to the inescapable conclusion that an electron and a positron may be converted into two gravitons, i.e., two gravitational waves, as well as into two photons. The probability of this type of conversion is very low under the conditions of density and temperature known to exist in planets and stars. The existence of regions which are in a special state is not excluded, however. Gravitational transmutations may proceed with greater facility there.

The existence of special regions is also suggested by the difficulty of explaining the formation of elements having medium or heavy atomic weight. Nuclear reactions undoubtedly proceed in the sun and other known stars; but at temperatures prevailing there (20×10^6 degrees in the interior of the sun) the more complex atomic nuclei, including those of moderate weight, cannot form. To explain the formation of elements up to uranium, one must assume a superdense state in which conditions of extremely high density reaching intranuclear magnitudes exist. The density would have to be of the order of 10^{14} grams per cubic centimeter (100 million tons per cubic centimeter) and the temperature 10^{10} - 10^{11} degrees for the average energy per particle to be of the order of 10^7 Mev (Chandrasekar, Weizsaecker, Vatagin, Ivanenko). Under these conditions the equilibrium distribution of matter among nuclear isotopes would correspond to that actually observed and described by the Goldschmidt curve. The question arises of whether the existence of special regions cannot be connected with the beginning of the expanding universe. The special, superdense states may be highly transient.

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The existence of subparticles lighter than the lightest known elementary particles is not being debated in contemporary science. If such subparticles are ever discovered, they will resemble the elementary particles now known as little as the latter resemble indivisible atoms or molecules of chemical elements. Although theory cannot predict at present just how many kinds of elementary particles actually compose matter, there can be no doubt whatever that the bulk of matter and the known universe consist essentially of the eight known particles and two fields, gravitational and electromagnetic. It is interesting to note that the existence of positrons, mesons, and neutrinos has been predicted on theoretical grounds. Contemporary theory, in addition to the almost-discovered neutrino and neutretto (neutral meson), predicts above all the existence of the antiproton. The existence of heavy superparticles (Ivanenko) is not excluded by modern theory. Such particles would have masses several times higher than those of nucleons, if the field hypothesis of mass is assumed to be true. Then the mass of superparticles would be determined by the field of nucleons, just as the mass of nucleons is essentially determined by the meson field and the mass of electrons by the electromagnetic field. It is possible that the heavy particles observed by Alikhanov and Alikhan'yan are superparticles of just this type.

The operation with point particles, which is accepted at present, leads to the great difficulty of having to assume that all fields generated by these particles (gravitational, electromagnetic, mesonic) have infinite energy. Various solutions of this difficulty have been proposed. One of the suggestions (Ambartsum'yan, Ivanenko, also Snyder) was to modify the geometry of infinitely small distances by assuming discontinuous "quantum" space.

The development of nonlinear electrodynamics and mesodynamics is still in an early stage (Ivanenko and Sokolov have contributed to work in this field). The fact that the linear field theory finally leads to the necessity of a nonlinear generalization of field equations, if only by introducing corrections, apparently indicates that the relativistic quantum theory is not quite self-sufficient and complete. From the purely physical standpoint, the linear field theory implies very low field intensities. While a nonlinear generalization is demanded by the theory, there is no particular necessity for including higher derivatives, although this is not forbidden by the theory. A special variation of the theory with the inclusion of higher derivatives has been proposed by Bopp and Podol'skiy to obviate the difficulty of infinite energy of an electromagnetic field generated by a point charge. The theory was developed further along these lines for the mesonic field in order to deal with the so-called dipole difficulty, which expresses itself in an excessively rapid increase of potential energy of nucleon attraction at the smallest distances (Ivanenko and Sokolov).

One may remark in this connection that limitation of the range of derivatives to the lowest derivatives means, from the physical point of view, that the variation of all fields is relatively slow and that processes having extremely high frequency must be neglected.

There are two types of interaction. The first involves the emission or absorption of a field or particle by another particle or field due to the existence of a bond between them which is commonly referred to as due to a charge. (From this point of view, mass is regarded as a gravitational charge.) The second type of interaction agrees more closely with the conventional concept of "interaction," implying as it does the action of one particle on another through a field or a third particle which transfers the action. From the point of view of the quantum theory, the second type of interaction involves an exchange of field quanta, such as an emission of a photon by a proton and its absorption by an electron. On the statistical level such an exchange of quanta results in the relationship expressed by Coulomb's law and its generalization for moving particles. If there is an exchange of gravitons, Newton's law and its corresponding generalization result.

As pointed out by Soviet theoreticians (Ivanenko, Sokolov, also Tamm), this model of interaction by means of quanta of the usual fields (electromagnetic and gravitational) can also be applied to interactions transmitted through particles of finite rest mass, such as the electron-neutrino pair. The whole contemporary theory of interaction between particles is based on this assumption. Clarification of the composition of the atomic nucleus and the nature of the neutron as an elementary particle and explanation of beta-decay by the generation of electrons or positrons which formerly did not exist in the nucleus (Ivanenko, Gapon) are followed by the cardinal problem of nuclear physics, that of clarifying the force which holds the nucleons together It is obvious that neither magnetic nor gravitational forces can hold the nucleus toegther. The original assumption that interaction between protons and neutrons takes place by transfer through electron-neutrino or positron-neutrino pairs is open to criticism. The forces resulting on the basis of this theory have the right characteristics: they have a short range, i.e., decrease rapidly with distance, and they depend on distance, spin direction, etc. However, they are much too weak to explain the tremendous forces holding the nucleons together.

Further progress is due to the hypothesis of Yukawa, who continued the work begun by Soviet scientists. Yukawa postulated that particle pairs are really single particles, the so-called mesons. The theory of nuclear forces made it possible to predict that the meson mass must be 150 times the electron mass, and that the meson must be unstable and have integral spin. The fact that all these predictions could be verified after the actual discovery of mesons in cosmic rays indicates the accuracy of the postulated model of the nucleus and the action of nuclear forces. At present there can be no doubt whatever that interaction between nucleons takes place through the mesonic field. In other words, protons emit mesons which are absorbed by neutrons; protons in turn absorb mesons emitted by neutrons. Notwithstanding the considerable advance in nuclear theory, there still is no law describing nuclear forces which compares in accuracy and precision with Coulomb's law or Newton's law.

Both positive and negative mesons have been discovered by Anderson and Neddermyer. The existence of neutral mesons which also may transmit nuclear forces is not yet quite certain. Mesons of different masses (the main component of hard radiation with a mass about 200 times the electron mass m; others with masses equal to 300-400 m and about 900 m) have been discovered recently in work done outside the USSR. The research team of Alikhanov and Alikhan'yan confirmed these results and indicated the presence of still heavier mesons and superparticles heavier than nucleons. It is probable that some types of mesons yield lighter mesons after spontaneous decay. Mesons of standard mass about 200 m also apparently decay, in this case with the production of a electron-neutrino or positron-neutrino pair. In a state of rest, these mesons have a half-life equal to $2 / 10^{-6}$ second. Some negative mesons are apparently absorbed by nuclei, at least as far as heavy and medium elements are concerned, while positive mesons decay. Quite recently, mesons (more than 10 years after their discovery in cosmic radiation) have been obtained under laboratory conditions by the bombardment of various atomic nuclei with 400-Mev alpha particles accelerated in a gigantic synchronous cyclotron.

The spin of mesons has not yet been definitely established. Most probable is the existence of pseudoscalar particles with spin 0 and of vector particles with spin 1. In the near future great progress may be expected in the study of the properties of mesons. A greater clarification of their ability to transfer nuclear forces will also result. By virtue of the two types of interaction mentioned above, all particles and fields act upon each other, of course. Thus, because of the virtual dissociation of the neutron into a proton and negative meson, a neutron placed in an external electromagnetic field will not at all be indifferent to it. On the contrary, in a constant magnetic field a system that is dissociated in this manner, and consequently the neutron itself, will exhibit negative magnetic moment due to the magnetic moment of the meson. As far as the magnitude of that moment is concerned, the positive magnetic moment of the heavier proton will be smaller (Wick, Heitler, Yukawa). In the external field of an electron a neutron will behave like a system which has a certain effective, although lowered charge (the point charge of a proton has a greater effect that the diffuse negative charge of a meson cloud). In consequence thereof, as shown by the author (Ivanenko), there must be attraction between electron and neutron. Recent experiments by Fermi, Marshall, and Rabi and his collaborators on neutron scattering by atomic electrons apparently confirm the existence of the predicted small attraction.

If we consider macroscopic accumulations of matter in the form of solid bodies and liquids, we find that much remains to be done in this field while the field of atomic research has advanced rapidly. Remaining to be done are unsolved problems in connection with superconductivity, the theory of crystal formation from atoms, and several other important branches of physics presenting obstacles to experimental and theoretical treatment. In regard to the theory of crystals, an important recent advance may be credited to A. A. Vlasov; M. Bori's name should be also mentioned in this connection.

The emission of light by accelerated electrons was predicted by Ivanenko and Pomeranchuk, and the theory was further developed by Artsimovich and Sokolov. This light emission, which is distinct from the Cherenkov effect (emission of light by electrons moving with constant velocity exceeding the phase velocity of light in some medium), could be confirmed recently by the work of Pollock and his group on electrons accelerated in the newest experimental installations of the betatron and synchrotron type.

It must be noted that modern theory predicts the possible formation of new kinds of atomic systems from elementary particles. For instance, an electron and a positron revolving around a common center of gravity may form a positronium atom. This system, which should have the dimensions of a hydrogen atom, must be unstable because an electron plus a positron would be converted into two photons within 10^{-10} second in the case of para-positronium with anti-parallel spins. Ortho-positronium with parallel spins would emit three electrons on annihilation and have a half-life approximately 100 times longer than that of para-positronium. A molecule of positronium consisting of two atoms and analogous systems built up of a meson and an electron (mesonium) or two mesons (bi-meson) are also possible. All these systems must have the characteristic of a very short half-life. Their half-lives approach the limit of contemporary experimental procedures, however, so that one may count on the discovery of metastable systems of this kind in the near future. Notwithstanding the short life of the systems in question, the formation of mesonium and positronium must play a considerable part in the fate of the meson and the positron, e.g., by modifying conditions of scattering at the end of the free flight of these particles. A whole chapter of chemistry dealing with the postulated light unstable isotopes will presumably be developed in the not too distant future.

Fruitful methods of investigation which can eliminate many difficulties will be persistent analysis combined with sufficient depth of penetration and consideration of the inverse action of fields on particles (so-called extinction or damping). These methods are being applied in classical mesodynamics (Bhabha, Ivanenko) and in the quantum theory of mesons (Sokolov, Heitler, Wilson). They are also being developed at present in quantum electrodynamics (Lewis, Oppenheimer).

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